Chemical & Engineering NEWS

San Francisco meeting still slated despite hotel strike Page 7

Industrial gases
Recession has deflating effect

A Key Chemicals Review Page 11

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Cover: Union Carbide's recently expanded hydrogen plant at Ashtabula, Ohio

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Recession hits industrial gas markets

Demand for oxygen, nitrogen, and carbon dioxide is down, but take-or-pay contracts are maintaining profits; hydrogen continues to hold its own

Industrial gases are going through another of their cyclical downturns. Monthly volumes are way off for most of the gases, although as yet profits are holding up, according to producers, largely because of take-or-pay contracts.

"May was the watershed for gases," according to one producer. In May, he says, customers slowed their buying of merchant gases considerably. In its fiscal third-quarter report, Edward Donley, chairman of Air Products, the second largest U.S. industrial gas producer, says, "We continue to experience margin pressure in our industrial gas business in the U.S."

Actually, the problem did not start in May but rather began last fall with a downturn in steel production. Oxygen demand, which is tied closely to steel production, immediately felt the pinch. Total oxygen output was off 4.8% in second-half 1979 to almost 214 billion cu ft from the same period in 1978.

Producers say that the recession now has spread to two of the other gases—carbon dioxide and nitrogen. Carbon dioxide has indeed shown signs of slowing in official statistics. However, there are as yet no signs of a downturn in nitrogen output in figures published by the government. There is no sign of recession in hydrogen.

The question among producers is how long the effects of the downturn will be felt. For nitrogen and carbon dioxide, there is hope that things will get back on track later this year, but oxygen is another story. After the 1974–75 recession, it took until 1977 for oxygen output to reach 1974 volumes. This year, unlike 1974–75, merchant demand is also down.

During that recession, hydrogen was the only other gas to experience a drop in output, but it had more than recovered by 1976.

The downturn in gases has brought little reduction in planned capacity expansion. There have been a few deferrals and cancellations of air separation plants, but producers say that they still expect to see a 40% increase in oxygen and nitrogen capacity by the end of 1982. All new hydrogen projects are going ahead as are carbon dioxide investment plans.

This big expansion in oxygen capacity will be nothing compared to what will come later in the decade if the synthetic fuels industry takes hold. Industry estimates point to so much new oxygen capacity, mainly on-site, to supply the synthetic fuels industry that there will be a shortage of engineers to do the job.

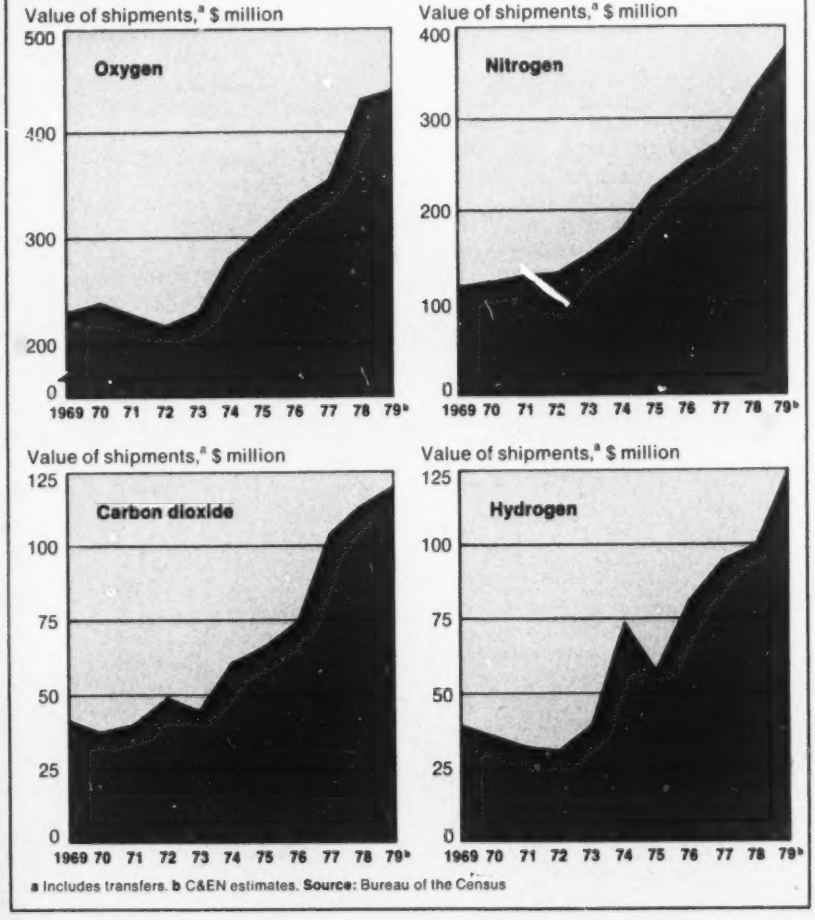
However, it will not be before 1985 or perhaps even later that this part of the industrial gas business begins even to sputter.

Also, argon, that small-volume by-product gas that once was thrown away, is still performing admirably. Because of lower use rates in air separation plants, argon production is off about 6% this year to 3.1 billion cu ft through May. However, producers say that they are still sold out. The price of argon increased another 5% in July to $2.00 per 100 cu ft. This was after an 8.6% increase the first of the year.

For a more detailed look at the 12-month outlook for oxygen, nitrogen, carbon dioxide, and hydrogen, see the following pages.

William Storck, New York

Combined value of industrial gases tops $1 billion



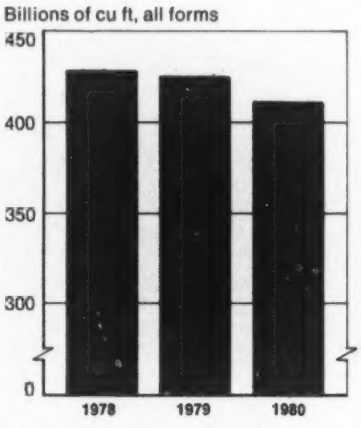
a Includes transfers. b C&EN estimates. **Source:** Bureau of the Census

Oxygen

O_2

- ***Demand down***
- ***Costs rising***
- ***Profits compressed***

PRODUCTION



HOW MADE

Separated from air at low temperatures

MAJOR USES (merchant)

Primary metal manufacturing 30%, health services 13%, metal fabricating 6%

FOREIGN TRADE

Negligible

PRICES

37.5 cents per 100 cu ft plus shipping and equipment charges (merchant)

COMMERCIAL VALUE

More than $440 million for total production, 1979

Oxygen, traditionally the largest-volume U.S. industrial gas, is in danger of losing that distinction in the near future unless its fortunes turn around.

Output of oxygen dropped 1 billion cu ft, or 0.2%, in 1979 from 1978's 427 billion cu ft. Production of nitrogen was only 14 billion cu ft behind oxygen and closing rapidly. Needless to say, the ongoing recession in the automobile and steel industries is largely to blame for oxygen's woes.

As in other chemicals, 1980 started out well for oxygen. Production for the first three months increased 8% to 113.4 billion cu ft. Then, suddenly, buying stopped. Production for April and May this year dropped 8.3% below that for the same months last year, bringing oxygen's growth for the first five months of 1980 to 1.2%.

Producers say that this gloomy situation continued in June and July. Figures are not yet available from the government for these months, but producers say that demand in the important merchant market is down about 10% from last year's levels.

An even bigger blow to oxygen's profitability has been energy costs—both in production and distribution. Air separation is a big user of electricity, and producers say that power costs have climbed as much as 30% in some parts of the country in the past year. The situation is bad enough, they say, to make them consider a more regionalized pricing system for merchant oxygen. In the past, oxygen has been priced on a national basis.

Pricing in no way has kept up with costs in the past year. While electricity rates were increasing 30%, prices were rising only a little more than 10% for merchant oxygen to 37.5 cents per 100 cu ft, on a large-volume liquid basis. And even this increase had to come in two stages—on Jan. 1 and July 1.

Even delivery of merchant oxygen is changing because of the cost pinch. It has long been a rule of thumb that delivery could be profitable only within a 200-mile radius of the air separation plant. But because of rising fuel costs for trucks, this radius is shrinking to the point where it is now closer to 150 miles. This is making it increasingly important to be the low-cost producer in a given competitive area.

Fortunately for producers, oxygen profits are well buffered by take-or-pay contracts in the tonnage or on-site side of the market. In this situation, large users of oxygen contract to take the gas produced in air separation plants on their property and have to buy it whether they use it or not. Profits are further protected in the tonnage area by escalation formulas written into these contracts that provide increased prices in the event of rising costs.

One big change that producers have been able to effect is adding merchant capability to tonnage plants. In the past, customers of on-site gas plants were very jealous of the gas produced there and were reluctant to allow any of it to be sold on the merchant market. Now gas producers are designing up to 30% merchant capacity into on-site oxygen plants. This capacity is dedicated to the merchant market and is not intended as a possible buffer against increased use by the on-site buyer. If the on-site customer wants it, it can be bought only at higher merchant prices. It will not be absorbed into the contract.

In fact, one of the problems this year is that supplemental sales of oxygen to steel producers have slacked off. In the past couple of years, such supplemental sales to steel producers, who have needed more oxygen than their on-site plants could generate, have soaked up much excess liquid oxygen capacity. This year, however, these supplemental sales have evaporated as steel production has fallen.

One trend that is emerging is the use of pressure swing adsorption units to produce oxygen by noncryogenic means. These units, which can be used for small installations, only now are starting to be used in the U.S.; they have been in use in Europe longer. Originally they were used in the U.S. for oxygen generation for wastewater treatment plants, but they are now gaining acceptance in remote locations for small-volume users. Their only drawback seems to be that they produce a relatively low grade oxygen of little more than 90% purity.

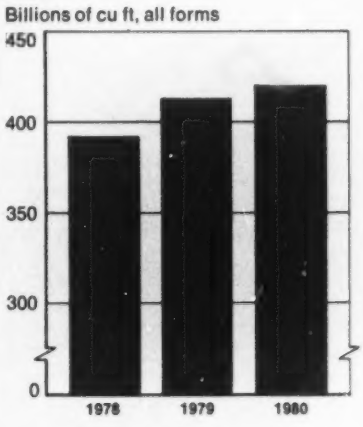
Oxygen producers seem to have pretty well given up on the remainder of 1980 for a turnaround. They are now looking toward 1981 to see their product finally get back on the growth track.

Nitrogen

N_2

- ***Growth easing***
- ***Prices up***
- ***Profits squeezed***

PRODUCTION



HOW MADE

Separated from air at low temperatures

MAJOR USES (merchant)

Blanketing atmospheres—chemical processing 14%, electronics 15%, metals 5%; freezing agent 21%; aerospace 8%

FOREIGN TRADE

Negligible

PRICES

34.5 cents per 100 cu ft plus shipping and equipment charges (merchant)

COMMERCIAL VALUE

More than $375 million total production, 1979

Last year was rather disappointing for admittedly spoiled U.S. nitrogen producers, and 1980 could be worse. Production of the second-largest-volume industrial gas in 1979 grew only 5.4% from 1978 to 413 billion cu ft. This is less than half its compound 10-year growth rate of 12%.

This year, the growth rate will slow even more, according to producers. Production in 1980 probably will be up no more than 2% from 1979, they say, to perhaps 420 billion cu ft.

Producers don't think much of the second half of 1980, evidently. For the first five months of 1980, total nitrogen production was up 17% over the comparable period of 1979. Thus, to achieve only 2% growth for the full year, production is going to have to fall off dramatically in the second half. Production growth during the first part of the year is traditionally ahead of the growth rate for the entire year, but it would be remarkable if the 17% production increase for the first five months of this year was turned into only a 2% increase at year's end.

For the moment, however, the increase in production through May has resulted in a new, possibly temporary, leader in industrial gases. Nitrogen production during that period was 193.4 billion cu ft, 6% higher than oxygen production at 181.3 billion cu ft.

The growth in nitrogen seems to be led by its oil field uses, where it is being used to maintain pressure in oil reservoirs. Previously this had been done by natural gas. Nitrogen also is being used as a carrier for other materials injected into oil wells. Producers say that nitrogen's possibilities in enhanced oil and gas recovery are just starting to be realized, although there is still some question as to how well it will work.

In many cases, nitrogen is replacing carbon dioxide in oil field use. Nitrogen producers attribute this to the relative economics of the two gases (nitrogen is cheaper, they say) and to possible corrosion problems with carbon dioxide.

This year, refrigeration use of nitrogen for food may grow as more consumers use fast-food restaurants or eat frozen foods at home. Although nitrogen has taken some of the food-freezing market away from carbon dioxide, producers indicate that there always will be a place for each. Some foods seem to have a particular compatibility with one or the other.

However, the growth in freezing and oil field uses will be somewhat offset by a slowdown in nitrogen's use as a blanketing atmosphere in metal production. This use is expected to be lower than in 1979, since the metals industry is not performing so well as it did last year. Chemical process use probably will hold about even.

The price of nitrogen is increasing but is not keeping up with costs. During the past year, the price of merchant nitrogen increased 15% to 34.5 cents per 100 cu ft from 30 cents last year. Industrial gas companies say that production costs have increased much faster than this. For the U.S., electric power rates are up 30% from last year; producers say rates have doubled in southern California in the past six months alone. The situation is bad enough, they say, to make them consider a change in traditional pricing policies.

Thus, like many products in the chemical industry, nitrogen is facing a profit squeeze. The 34.5-cent current price is for the largest users of liquid nitrogen. Charges are added for transportation and handling equipment.

The price of large tonnage or on-site nitrogen is much lower and is specified in long-term contracts containing escalation clauses for increased costs. Contracts for on-site nitrogen contain take-or-pay clauses, thus to a large extent protecting producers' profits on the gas.

This year producers broke the traditional pattern of increasing prices only once during the year. For nitrogen as well as oxygen, prices were increased on Jan. 1 and again on July 1. In the past, there was usually only one price increase—in the spring.

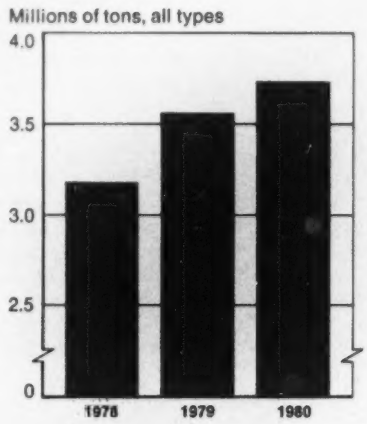
This switch could signal a more aggressive pricing policy in the future with tabs increasing as costs mount. Producers are also talking about regionalized pricing to make up for higher utility rates in different parts of the country. Regionalized pricing has been a standard with carbon dioxide; prices are lower in the Midwest than they are in the West and East, but the practice has not been tried, at least in recent years, for nitrogen and oxygen.

Carbon dioxide

CO_2

- ***Market still up***
- ***Feedstock pinched***
- ***Prices up slightly***

PRODUCTION



HOW MADE

Recovered from synthesis gas in ammonia production; recovered as by-product in substitute natural gas production; recovered as by-product from fermentation ethanol production; recovered from natural wells

MAJOR USES

Refrigeration—food 37%, industrial 15%; beverage carbonation 25%; other industrial uses 22%

FOREIGN TRADE

Negligible

PRICES

About $61 to $62 per ton plus equipment charge; higher on East and West Coasts

COMMERCIAL VALUE

More than $120 million for total production, 1979

Carbon dioxide finally has hit a snag, with slowed growth in both 1979 and 1980. In 1979 production grew only 5.7% for all forms, which totaled 3.53 million tons. Although many other chemical producers would be happy with such an increase, carbon dioxide producers see it as a significant slowing. In 1978 carbon dioxide production increased 12.9%. Output of this industrial gas, the third largest by volume in the U.S., grew at a compound annual rate of 11.7% between 1969 and 1979.

Because of this reduced growth rate, carbon dioxide fell from 21st to 23rd place on C&EN's list of Top 50 chemical products in 1979.

However, producers of merchant carbon dioxide were not too concerned. The merchant market still grew about 12% in 1979. Merchant carbon dioxide makes up about 20% of total U.S. production. The other 80% is used captively in large volumes such as in oil fields and for pH control, which doesn't affect the merchant market.

For first-quarter 1980, it looked as if things were going to get back on track for carbon dioxide. Total production increased 13.4% from first-quarter 1979 to nearly 767 million tons. However, in April, production fell to 254 million tons, a 1.7% decrease from April 1979. And producers are afraid that May and June were even worse.

Producers say that the merchant market is still growing, but even it is causing them to worry. Merchant sales for all of 1980 probably will be up no more than 5%—this after growing at about 15% per year for the past decade and gaining 15 to 20% in the first quarter over the same period last year.

One of the ironies of the merchant business this year is that the heat wave in the South—which one would think would help the gas in its refrigeration uses—may actually hurt merchant sales in a few months. The reason is that poultry, which is frozen with carbon dioxide, is dying before it is mature enough to be sold for food. Thus, much of it will never reach the market.

For the longer run, however, use of carbon dioxide for freezing is still growing. Producers find that during a recession, fast-food outlets become more popular. These outlets use food frozen with CO_2. Then too, the increase in the number of working women and the growing use of microwave ovens has proved to be a boon to carbon dioxide producers.

Another growing use for merchant carbon dioxide is in oil fields, up to now a captive market, where it is used for miscible polymer flooding and for treating newly drilled oil wells. This is a relatively new use for merchant carbon dioxide. In this use, however, it competes with nitrogen.

Carbon dioxide also is finally gaining acceptance for pH control of wastewater. This use has been talked about for years but has been slow starting up. Most utilities have used lime. As one carbon dioxide producer says, "The people in charge of the utilities usually won't change unless they are forced to."

Merchant carbon dioxide capacity has increased to about 16,000 tons per day, but this figure is misleading. In spite of the increase, some producers feel that there are still supply problems. The main reason is that effective production capacity depends largely on ammonia output. And since ammonia production has had its ups and downs in the past two years, effective capacity for by-product has also been sinking to where it is now—about 80% of nameplate.

This situation may not last long, however, producers hope. They are banking on being able to recover carbon dioxide from the big new fermentation process ethanol plants that will be coming on stream as part of the gasohol buildup. Carbon dioxide makers say that there will be enough of this by-product carbon dioxide to lower costs significantly and to increase profit margins.

If there is a tight supply of carbon dioxide, it has not been reflected in the price. Merchant carbon dioxide is still listed at the same price it was last year—$60 to $61 per ton plus surcharges for the Northeast and western parts of the country—but this price may not last long. A price increase of 9% is in the works.

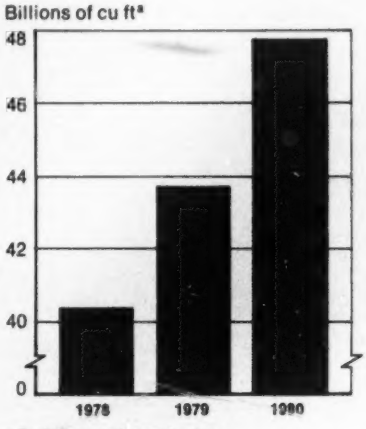
But this increase will probably do little more than cover rising production costs. It is nowhere near the 40% price increase that producers got between 1978 and 1979. After the present recession yields to recovery, producers may try for another big hike to increase margins.

Hydrogen

H_2

- ***Demand up***
- ***Capacity expanding***
- ***Prices up***

PRODUCTION



a Excluding captive production.

HOW MADE

Steam reforming of natural gas

MAJOR USES

Chemical processing 63%, metallurgical uses 37%

FOREIGN TRADE

Negligible

PRICES

91 cents per 100 cu ft in 13,000-gal lots (liquid)

COMMERCIAL VALUE

More than $125 million for total merchant production, 1979

Hydrogen is the one large-volume industrial gas that producers are optimistic about this year. Output of merchant hydrogen is expected to grow more than 9% in 1980 over last year to about 47.8 billion cu ft.

Since 1971, merchant hydrogen production has grown at an average annual rate of 10.6%. So a 9 to 10% growth rate this year represents a little slowing, but not enough to cause any concern among producers.

Actually, merchant hydrogen is just a small part of total hydrogen production. Much more hydrogen is produced—mainly in the metallurgical industry—by small on-site units. Production from these units is not reported, and no one knows just how much this production is. Estimates place such production anywhere from four to 10 times total merchant hydrogen output.

These small producers of on-site hydrogen offer an opportunity for growth to merchant hydrogen producers. Much of the growth for merchant hydrogen in the metallurgical area has been in the replacement of these small on-site units.

The biggest area for growth, however, is in chemical processing for products such as plastics, pesticides, and chemical intermediates, notably aniline. In 1977 chemical processing took about 50% of merchant hydrogen production; this year it will take about 63%.

The reverse is true for hydrogen use in metal processing, where it has declined from 50% of all hydrogen production in 1977 to about 37% of production this year. In metal processing, hydrogen is mixed with nitrogen to form blanketing atmospheres. With use down in this area, producers say that they are depending to a great extent on replacement of the on-site units for market growth.

There are three kinds of merchant hydrogen—gas, liquid, and pipeline. Hydrogen gas is made by a number of companies and is shipped in small "tube trailers" holding about 150,000 cu ft.

Liquid hydrogen, which is the most profitable and fastest growing segment, is made by only three U.S. companies—Air Products, Union Carbide, and Airco. It is shipped by tank car, truck, or barge. Economies of scale make it possible to ship liquid hydrogen up to 1000 miles from the plant. By comparison, gaseous hydrogen can be shipped only about 150 to 200 miles economically.

The third kind of merchant hydrogen is that shipped by pipeline. Air Products has the only active hydrogen pipeline in the U.S. This 100-mile pipeline system (which also carries carbon monoxide) serves chemical processors along the Houston Ship Channel.

Right now there seems to be some tightness of supply of liquid hydrogen. Producers are looking forward to some capacity expansions. Present liquid capacity stands at about 128 tons per day. This includes the doubling of capacity this year at Union Carbide's Ashtabula, Ohio, plant to 17 tons per day.

There will be two more plants serving the U.S. liquid hydrogen market within the next two years. Carbide is building a 20 ton-per-day plant at Niagara Falls, N.Y., slated to come on stream in late 1981 or early 1982. And Air Products is building a 15 ton-per-day plant at Sarnia, Ont. Most of the output from this plant is slated for U.S. markets. The Sarnia plant will use hydrogen from a Dow Chemical chlorine-caustic plant at Sarnia for feedstock.

There is currently a wide range in prices for liquid hydrogen, from 91 cents to 98.5 cents per 100 cu ft in 13,000-gal lots, the industry standard. These prices are only about 9% over last year's price, hardly matching cost inflation and certainly not reflecting a tight supply. The price differences, according to some in the industry, come about because of very favorable raw materials contracts for some producers.

The price of pipeline hydrogen is about $3.00 per 1000 cu ft, delivered. This price is for the largest users; smaller users pay more. However, there are additional equipment charges and customers are, at least in part, on take-or-pay contracts. Economics of scale in production and less capital cost in the distribution network make it possible to sell pipeline hydrogen at about one third the price of liquid hydrogen.

For the remainder of the year industrial gas producers are hoping that hydrogen will help alleviate the declines in the other industrial gases. As one producer says, "As yet, hydrogen is unhindered by the recession."

Japanese chemical production turns down

The graphs on the left show that since the first part of last year, production in most segments of Japan's chemical industry has been climbing relentlessly upward.

What the graphs do not show—because the index data for the second quarter of 1980 aren't available yet—is that Japanese chemical production started turning downward around March or April. This is particularly true of petrochemicals and their derivatives. And indications are that Japanese chemical companies will face tough sledding throughout the rest of the year. As a result, their profits, which returned to some semblance of respectability last year, will probably take a beating once again.

For some companies, profit problems already are appearing. Mitsubishi Petrochemical, for instance, reports a 30% drop in pretax profits for its latest six-month reporting period that ended in June.

The problem is that while basic petrochemical producers in Japan were on last year's production binge they were chasing a demand that didn't really exist. The brisk "demand" that prompted record production of several petrochemicals was, in most cases, an inventory buildup on the part of many major customers. Well aware that raw material costs, particularly for naphtha feedstock, were constantly rising, many downstream customers began stockpiling their own petrochemical raw material requirements to beat the price increases that they knew would come.

In response to this inventory buildup, Japanese ethylene producers turned out a record 4.8 million metric tons of product last year, a 9% increase over 1978. Output of the major aromatics rose 6 to 8%. Production of the major thermoplastics soared—polyethylene up 23%, polyvinyl chloride 31%, polystyrene 19%, and polypropylene an impressive 37%.

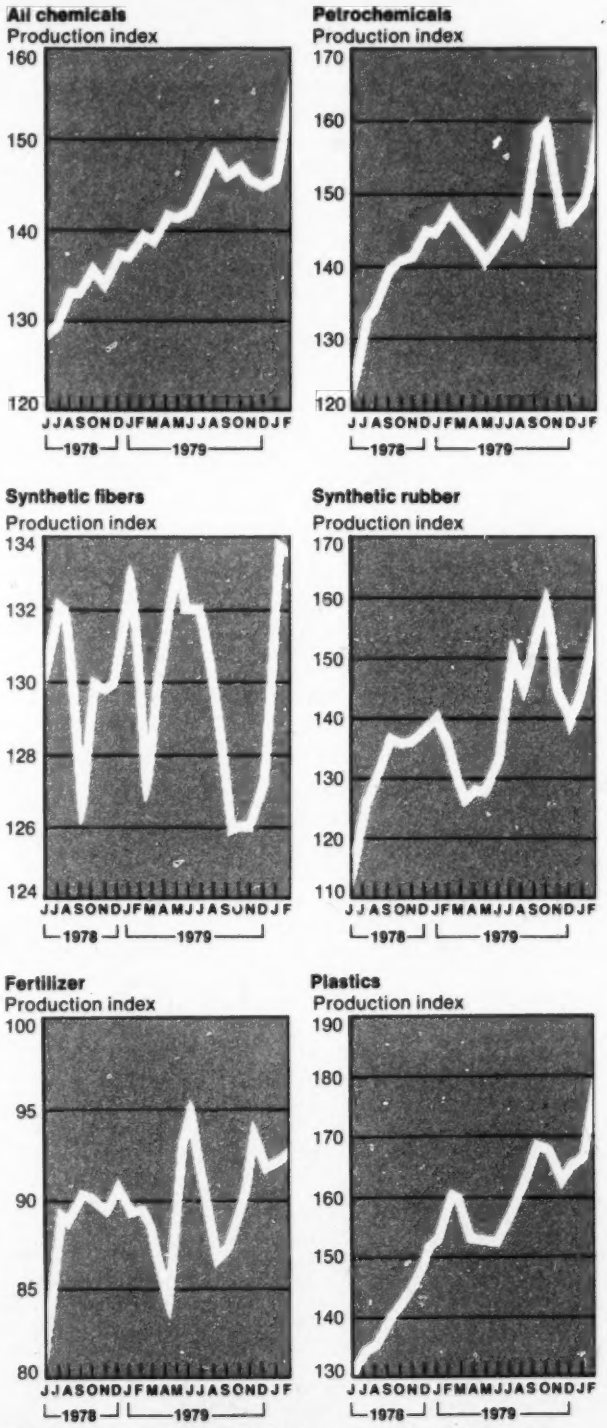
Now, the real demand as well as the artificial demand that triggered last year's production surge is reversing itself. And with the tailoff in demand becoming painfully obvious, Japanese petrochemical producers are starting to trim production.

As the bellwether of the Japanese petrochemical industry, ethylene provides a good indication of what is happening there. In June, ethylene output was only 374,300 metric tons, down 4.8% from May and down 4% from May 1978. This marks the first time since April 1977 that ethylene production was lower than in the corresponding month of the preceding year.

Meanwhile, ethylene's future is even bleaker. The Ministry of International Trade & Industry estimates that ethylene production in the third quarter (July-September) will be 10% lower than the same period last year.

According to some Japanese petrochemical experts, the growing imbalance between supply and demand may have some serious repercussions. Petrochemical producers, usually reluctant to cut production for fear of losing a share of a highly competitive market, now realize that some adjustments have to be made. But if the necessary curtailment isn't done smoothly, the results could be disastrous.

Earl Anderson, New York



Note: Base year for all indexes, which are seasonally adjusted, is 1975 = 100.
Source: Ministry of International Trade & Industry

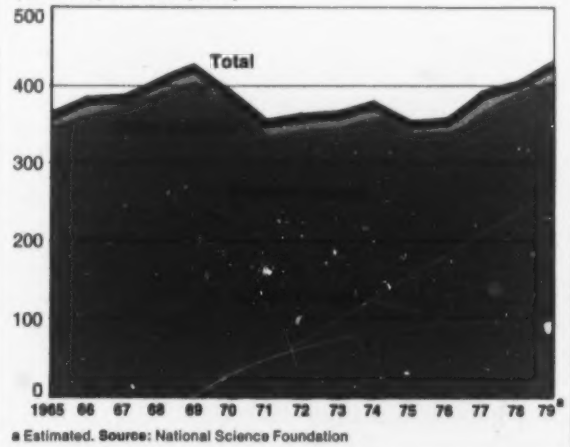
Support and manpower for basic chemical research

G. G. Meisels
University of Nebraska

Modern society is inextricably intertwined with and heavily dependent on technology. We have come to take for granted a life expectancy of 70 years or more, relatively little physical pain under normal circumstances, first-class health care, sufficient food, safe and comfortable housing, rapid and convenient transportation, and numerous other comforts and conveniences. All of these are, directly or indirectly, a consequence of the revolutionary technological developments of the past century.

It is not overdramatic to assert that the way of life we know today cannot exist without continuing technological strength. Even the arts and humanities and our ability to address social ills depend on the availability of excess resources, those that need not be devoted to sustaining acceptable living conditions; only further technological developments will provide the underpinnings for overall societal development without a reduction in the average standard of living. Our hope to improve life rather than force a reversion to life styles long past hinges on a technological approach to the solution of current problems, such as those caused by shortages of energy supplies and by pollution.

Support for basic research in chemistry has changed little in a decade



a Estimated. **Source:** National Science Foundation

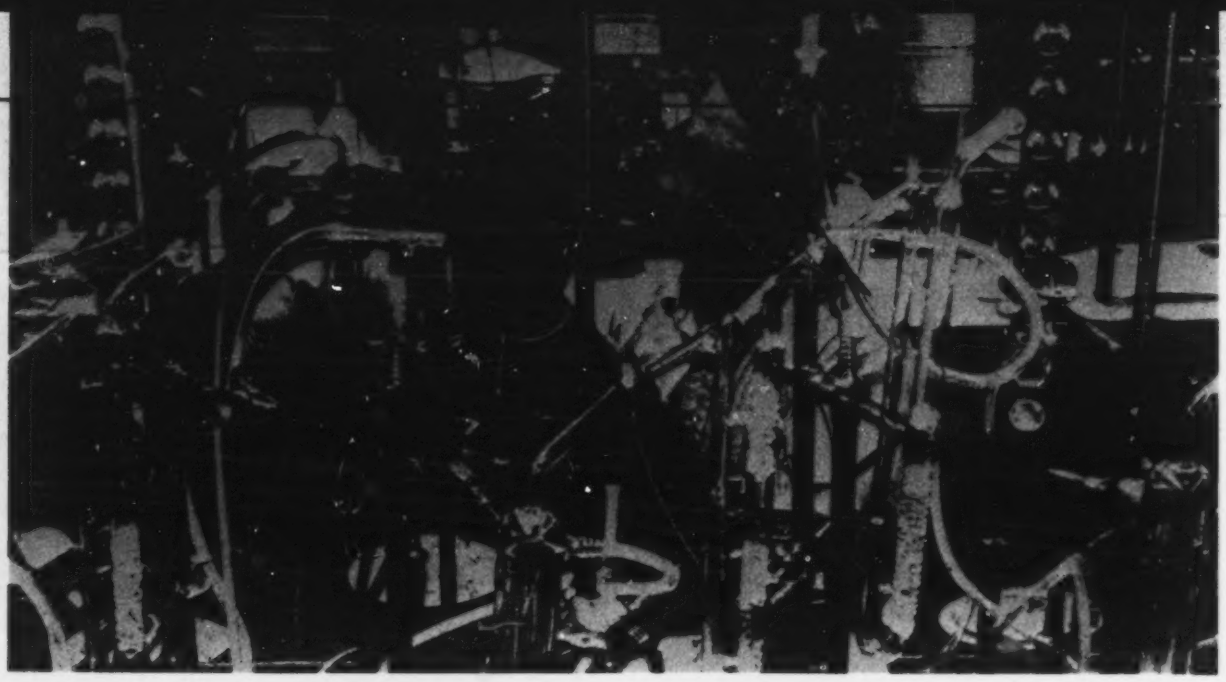
The technological revolution of the past century was firmly footed in a rapidly increasing reservoir of basic knowledge produced through basic research. No discipline is more dependent on such basic information than chemistry. During the past few years, however, increasing concern has been expressed about the reduced rate of innovation in science generally and in chemistry in particular.

This has raised several questions about basic research in chemistry. Has the pool of basic chemical knowledge expanded at a constant, increasing, or decreasing rate? How has basic research fared in comparison with applied research, and how has research in chemistry compared to research in other fields? Has it changed, in comparison with nonresearch expenditures? Is it possible, on the basis of current patterns, to project what the future may hold? Is this future acceptable, or should a deliberate effort be made to seek change?

Basic research may be defined as "original investigation for the advancement of scientific knowledge not having specific commercial or mission end-use objectives, although such investigations may be in fields of present or potential interest to the company or agency."

There is considerable (but unnecessary) debate on the merit of basic or fundamental research. Actually, good basic scientific research is simply an investigation of areas in which past study has not necessarily revealed potential applicability. Most arguments against basic research reflect a reluctance to look beyond immediate horizons. Basic research is an adventure into uncharted and unknown territory, with no guarantee of what may be found but always with the exciting prospect that it will lead to something really new. With a century of experience, we now can pursue case histories, trace developments, and state with confidence that basic research is essential for innovation; at least some basic research always has preceded major technological developments.

Case studies repeatedly have indicated this to be the case. For example, Monsanto's development in the



mid-1970's of a process for the synthesis of L-dopa, a drug for the treatment of Parkinson's disease, was based on results of basic research in catalytic hydrogenation performed at Imperial College, London, the University of New Hampshire, and the Université de Paris-Sud. Similarly, enzyme mapping, developed in the 1960's, was essential to the design, maximization of effectiveness, and eventual synthesis of diphenylether herbicides by Rohm & Haas. DDT, although first synthesized in 1874, was not used until the mid-20th century; similarly, 15 years of research elapsed between the discovery of the toxicity and the commercial development of organophosphorus pesticides. The crop savings resulting from these and other pesticides are estimated to fulfill the nutritional requirements of nearly 500 million people. Highly promising current developments include recombinant DNA technology and gas-phase ion clusters, studied for their relevance to solvation, which may hold the key to fusion power developments.

Perhaps one of the strongest arguments for research and development comes from research performed by economists. One study of profits, considered by many to be definitive, was published by H. G. Grabowski and D. C. Mueller in 1978 in *Bell Journal of Economics* and shows that, in research-intensive industries, returns on capital invested in R&D are well above the average for other types of investments. Simply put, investment in R&D is more profitable than that in other areas.

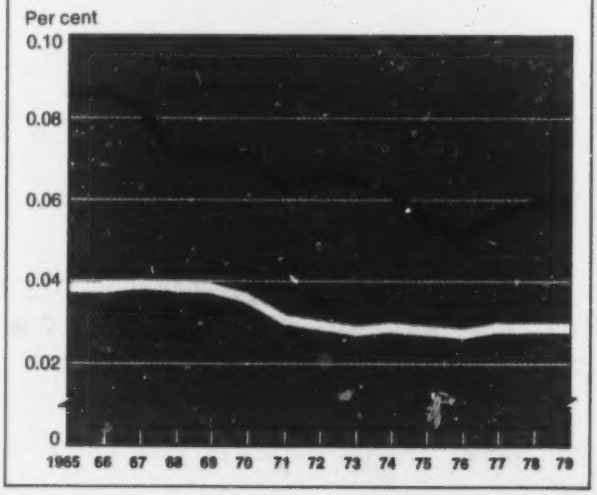
Before assessing the level of basic research effort in the U.S. over an extended time span and projecting it into the future, it is necessary to discuss what determines this level. Of course, it is not the level of effort that matters but its output. Unfortunately, changing patterns of publication, the increase in the number of scientific journals, and changes in the nature of research itself over the years all suggest that merely counting publications or patents is neither a suitable nor a reliable measure.

Research spending

Therefore, spending for basic research, in constant dollars, was chosen as the first measure of research effort. One advantage of doing so is the availability of data. These show that (in inflation-adjusted dollars) there has been no statistically significant change in the level of support for basic research in chemistry during the past 10 years. However, about 5% of total support has shifted to federal funds and away from industry since 1968. On the performance side, the proportion of total expenditures for basic chemical research at universities has not changed materially during the same period, but 6 to 8% of the total has moved away from industry and into nonuniversity laboratories supported by federal funds.

Basic research is less costly, per scientist, than R&D in general. According to National Science Foundation data for 1977, for example, industry spent $76,100 for each scientist and engineer engaged in all types of R&D. For basic research in chemistry, however, the cost was only $51,800 per scientist. In academia, basic research in chemistry is considerably less expensive, costing just $27,700 per scientist engaged. The low cost of basic research in universities probably is caused by a number of factors, such as the participation of graduate students who are not included in the manpower base used for the calculation or of postdoctoral fellows who also are still in

Chemical basic research gets a smaller share of GNP and the federal budget



Most Ph.D.[a] chemists engaged in basic research work at universities

Employer	1975 In basic research	1975 All activities	1977 In basic research	1977 All activities	1977 % of total work force
Universities and four-year colleges	2990	13,320	3796	13,698	33.7%
Industry	1976	18,278	2101	18,664	45.9
Federal government	620	1,697	639	1,810	4.4
Nonprofit organizations	380	1,071	319	1,048	2.6
Hospitals	120	387	104	446	1.1
Two-year colleges and secondary schools	—	1,082	—	1,094	2.7
Other employers	72	389	49	554	1.4
Unemployed or retired	—	2,560	—	3,336	8.2
TOTAL	6158	38,784	7008	40,650	100.0%

a Full-time equivalent. Source: National Science Foundation

the educational process, as well as unaccounted contributions of faculty release time.

It is reasonably clear that in the past the total performance of basic research has been limited by the funds available. It is not at all obvious, however, that this budget-limited model will be correct in the future. As demand for scientists to work in energy and other areas increases and production of Ph.D.'s, who direct basic research, decreases, the availability of qualified personnel rather than money may limit creative effort in chemistry in a few years. Then forecasts of future effort would require a manpower-limited model.

Manpower indicator

A second measure of research effort may be based on the assumption that the number of individuals engaged in basic research rather than the number of dollars spent on it is what determines the level of that creative endeavor. This approach implies, of course, that there is no change in the inherent creativity or ability of those who perform basic research—that is, that the quality and composition of the research work force has not changed.

Unfortunately, information on manpower is not nearly so extensive as that on spending. NSF initiated a biennial study in 1973 on the characteristics of doctoral scientists and engineers, but the data are reliable for only 1975 and 1977. (In the 1973 report, the number of Ph.D.'s found to be engaged in academic basic research is lower than the total number of postdoctoral fellows.) The annual salary survey of ACS members also provides relevant data, which compare well with those from NSF.

NSF data show that the full-time equivalent of 3796 Ph.D. chemists were engaged in basic research at universities and four-year colleges in 1977. Assuming that the approximately 2600 postdoctoral fellows in Ph.D.-granting universities that year were engaged full time in basic research and that the contributions to basic research from schools that do not grant a Ph.D. are small enough to be neglected, it appears that university faculty members spend about 30% of their time on research.

It is difficult to assess whether there has been a change in the manpower performing basic research in universities. Applying the 30% estimate for faculty time to data from the ACS "Directory of Graduate Research," a full-time equivalent of 3711 Ph.D.'s can be estimated as having been engaged in basic chemical research during the 1972–73 academic year, indicating a net increase of less than 1% a year between 1973 and 1977. (Data from the ACS directory should be quite accurate because all individuals in Ph.D.-granting universities are sampled through their departments.)

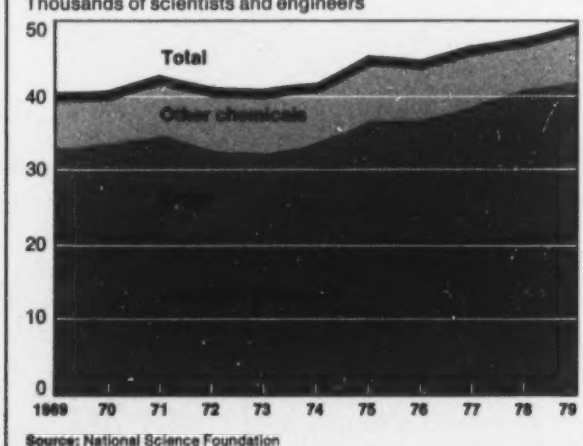
The apparent increase of 7% per year between 1975 and 1977 in Ph.D.'s doing basic chemical research at universities indicated by the NSF data may result from the inclusion of permanent staff people who are not faculty members. Because there was no similar increase in financial support for academic research, it well may be that the overall level of research effort remained constant while performance shifted from graduate students, whose enrollment has declined, to support staff, which ACS data indicate increased nearly 19% a year from 1973 to 1977. The increase cannot be ascribed to postdoctoral fellows; their numbers did not vary appreciably between 1973 and 1977. Recent evidence from ACS surveys strongly indicates, moreover, that the number of postdoctoral fellows has declined substantially since then.

The number of scientists and engineers engaged in basic research in industry can be estimated from the total number of individuals in industrial R&D, the fraction of industry R&D budgets devoted to basic research, and costs per scientist. Such an estimate indicates that in the 10 years through 1978, the number of chemists in basic research in industry has declined about 2% per year.

An estimated 40% of all R&D in industry is performed by Ph.D. chemists. The degrees held by individuals engaged in basic research in industry can be ascertained only indirectly; the most extensive survey, made of ACS members, includes a larger fraction of Ph.D.'s than their representation among all chemists in the U.S., as measured by NSF data. The data suggest, though, that in 1976 basic research in industry was performed by 5500 chemists, of whom about 2000 had Ph.D. degrees, 1300 M.S. degrees, and 2200 B.S. degrees. These proportions are very similar to those for chemists doing R&D overall. Apparently, the type of research being done is not material to the composition, by degree, of the work force doing it.

However, in general, individual chemists with a Ph.D. degree are much more likely to be in basic research than are chemists not holding that degree, particularly since only chemists with a Ph.D. are likely to be employed by universities. NSF data indicate that about 17% of all

Scientists doing R&D in the chemical industry have increased moderately



Source: National Science Foundation

Cost of conducting research in the chemical industry, per scientist, has not changed greatly

$ Thousands, constant (1972), per scientist and engineer	1978	1977	1976	1975	1974	1973	1972	1971	1970	1969
Chemicals and allied products	$48.7	$48.8	$49.7	$47.9	$48.5	$48.3	$47.1	$45.5	$46.8	$47.7
Industrial chemicals	55.7	56.5	55.8	53.1	54.7	55.4	54.0	51.2	51.2	53.0
Drugs	43.4	45.9	47.4	47.9	46.8	48.7	46.5	45.0	43.9	46.6
Other chemicals	42.1	38.3	38.0	34.0	39.0	32.1	33.4	37.0	36.6	33.6
All industry	52.3	53.7	54.0	52.3	54.6	56.0	55.3	53.2	52.6	54.8

Source: National Science Foundation

Ph.D.'s are engaged in basic research; in industry, 5.7% of B.S. chemists and 6.6% of M.S. chemists are similarly engaged.

Quality of work force

Creative effort and innovation do not depend on numbers only, of course, but also on quality. An alarming survey made last year by Douglas C. Neckers, chairman of the chemistry department of Bowling Green (Ohio) State University, of 75 universities and colleges indicates that graduate study in chemistry no longer attracts those undergraduates who are near the top of their class or highest in grade-point average (C&EN, Dec. 17, 1979, page 17). Such students enter medical school instead. In the period from 1964 to 1966, the grade-point average of chemistry majors entering medical school and those choosing graduate study in chemistry was the same. Since 1973, however, the average for medical students has exceeded the average for graduate students 0.3 point, well outside statistical error. Neckers' survey has been verified by a 1979 ACS survey, which shows that chemists with a B.S. degree who are working for a graduate degree in chemistry had a grade-point average of 3.37 whereas those who are in medical school had an average of 3.65.

Creative ability and grade-point averages are not necessarily closely related, but the average has long been used as a selection criterion because it is the only measure available. Neckers ascribes the lower average for graduate students largely to the heavy publicity given the short-term job market for chemists during the early to mid-1970's. He concludes that "students of lesser ability are being fed into the American research establishment in chemistry." If this is correct, it would signal a decline in the quality of new entrants into the chemical work force that demands strong countermeasures.

While the absolute level of basic research in chemistry, measured in terms of constant-dollar support and manpower, has been nearly constant during the past 10 years, the U.S. economy has expanded. It is important to ascertain, therefore, whether basic research has kept pace. If it has not, then basic research has decreased relative to other sectors of the economy, and with it innovation—provided that the latter is in some way proportional to the level of basic research or perhaps even only to total R&D effort.

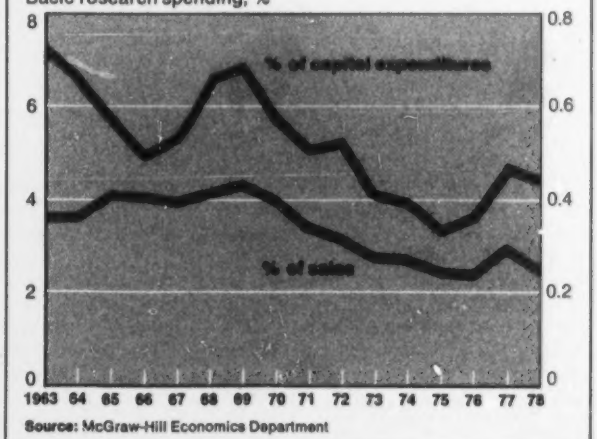
It is, of course, well known that the proportion of national resources devoted to basic research and to R&D in general has decreased substantially. The decrease of 5% a year in relative federal support of basic research in chemistry parallels a decline in support of other types of R&D. In the chemical industry, also, basic research has been de-emphasized, shrinking from 7.6% of total capital expenditures in 1963 to 4.5% in 1978, a decline of 3.5% per year, or from 0.37% of sales in 1963 to 0.25% in 1978, a decrease of 2.6% per year. Ironically, economic studies demonstrate that such a change affects profits adversely!

A conference of industrial and academic scientists sponsored last fall by Dow Chemical at Midland, Mich., brought to the surface perceptions that the reduction in innovation experienced by the chemical industry may be a result of government policies but also, perhaps, of a lesser dependency of academic research on industrial support, which has reduced the flow of information between universities and industry. But there may be a more direct cause: a marked decrease in the importance industry ascribes to basic research. This reduced emphasis probably also has contributed to weakening the academic-industry interface, although other causes for disaffection may exist, such as a lack of understanding of student actions and university and industry reaction during the turbulent Vietnam war years. Funding for university basic research from nonfederal sources, probably mostly from the states, has actually increased from 21% to 24% of the total in the past 15 years; therefore, increased federal support cannot be held responsible for weakening the academic-industry interface.

Future research levels

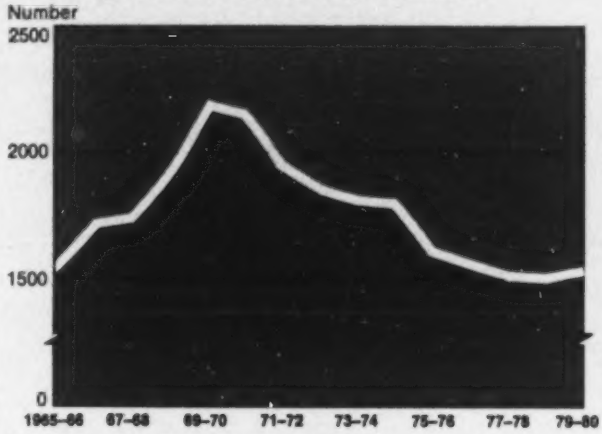
If past patterns of funding continue, there will be little if any change in the level of basic research, at least in terms of constant dollars. Increases planned in federal support are not quite at the inflation level and attempts to balance the federal budget may cause some further reduction, in constant dollars. Nor is there any indication that industrial funding for basic research is rising, although last year's Midland conference and future meetings of this kind may change the climate, and therefore the priority industry gives to basic research. There is also

Chemical companies put less emphasis on basic research



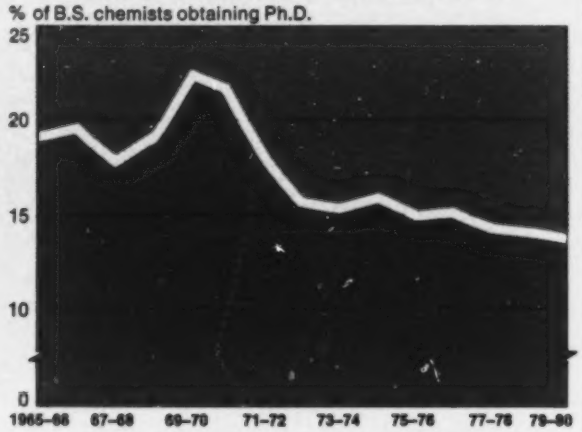
Source: McGraw-Hill Economics Department

Ph.D.'s granted in chemistry decline...



Note: Data for 1978–79 and 1979–80 are ACS estimates.
Source: National Center for Educational Statistics

...as smaller share with B.S. earn Ph.D.



Note: Data for 1978–79 and 1979–80 are ACS estimates; data represent Ph.D.'s granted in chemistry as a percentage of B.S. degrees in chemistry granted four years earlier. **Source:** National Center for Educational Statistics.

no indication that university faculties will increase at those institutions where research is a major faculty responsibility. Although there is considerable fear that student enrollment will begin to decline in the mid-1980's, this may well occur primarily at schools without a strong commitment to research. Staff reductions that eventually may take place, therefore, would not materially affect the level of basic research in universities. However, a continuing decline in chemistry majors and Ph.D. graduates nonetheless may reduce overall academic effort.

These arguments reflect a support-limited model. However, the employment for scientists and engineers generally is increasing. Technical employment in the chemical industry has increased at the rate of 1.7% per year since 1963. This is coupled with a replacement need of about 1.6% per year for Ph.D. chemists as a result of death and retirement. (The latter is a low estimate.) NSF estimates a future increase of 3.2% per year in industrial manpower in the physical sciences for a total demand of 4.8%. In addition, universities expect to increase their current manpower 5.2% this year.

Based on conservative assumptions that the number of employed Ph.D.'s increases 2.4% per year, a total demand of 4.0% for new Ph.D. chemists can be estimated, suggesting that about 1800 new Ph.D. chemists will be needed in 1981 and 1900 by 1985. Ph.D. production in the past few years has been below this level. If the number of Ph.D.'s awarded annually should continue to decline at a rate of 4.0 to 4.7% per year, as it did between 1970 and 1978, 1985 may see only about 1200 Ph.D.'s in chemistry graduating from U.S. universities. During the past three years, Ph.D. production appears to have leveled off at about 1530 annually, so the shortfall may not be so severe as this analysis would indicate. However, if indeed the guidance of basic research is primarily in the hands of Ph.D. chemists, the level of basic research may soon find itself limited by manpower, not by support funds.

These findings differ from a projection made by NSF last year which suggests that 7 to 9% of Ph.D. physical scientists will have to find employment outside their field between 1982 and 1987, compared to 7.1% in 1977. The discrepancy probably is the result of NSF's assumption that the number of doctoral scientists graduating annually will parallel the increase in R&D spending in industry, which it estimates will be 3.2% a year. Using this as-

Basic research subcommittee recommendations

Recognizing the importance of basic research, the ACS Council Committee on Economic Status, under the leadership of Samuel M. Gerber of American Cyanamid, last year appointed a subcommittee on basic research, chaired by the author, to investigate the level of such research and establish to what extent, if any, it has changed in recent years. The article on the adjacent pages is adapted from a fully documented report, available from the author (G. G. Meisels, Department of Chemistry, University of Nebraska, Lincoln, Neb. 68588), that was prepared as part of that investigation. Based on the findings of the report, the subcommittee on basic research recommends:

1. We urge those responsible for the support and direction of basic research in industry and the various branches of government, as well as state and national legislators, to provide continuity and stability for basic research and to isolate its fate as much as possible from the normal cycles of business performance, other budgetary priorities, and political pressures.

2. We ask for the dedication of additional resources to basic chemistry: that industry at least retain the balance of expenditures with respect to capital investments or sales prevalent in the early 1960's; and that the federal government at least keep the support for basic research in chemistry at the same proportional level within the total federal outlays it did in the early 1960's. (The net cost to the federal government to establish a policy such as the one recommended would be less than $60 million annually, or about 0.01% of the total federal budget.)

3. We recommend that the American Chemical Society establish an effective program to convey to high school counselors, college counselors, and college and university department chairmen in the sciences a clear and timely picture of the manpower balance anticipated for the future on the basis of current trends.

sumption, NSF projects that about 1900 Ph.D.'s will be granted in chemistry in 1982 and 2150 in 1987. This is highly improbable. This analysis indicates, on the basis of data for 1976 and 1977, that a shortage of doctoral chemists already should exist. This is supported by a number of observations. Peterson's annual guide to employment of scientists lists more than 100 companies that are seeking chemists, with doctoral chemists in analytical, physical, organic, and polymer chemistry in particular demand. The volume of classified advertising in C&EN for job openings available to chemists and engineers has been rising steadily, at least until very recently, to a level comparable with that of the mid-1960's. Last November, Betty M. Vetter of the Engineering Manpower Commission projected a substantial future demand for chemists. And the High Technology Recruitment Index compiled by consultants Deutsch, Shea & Evans of New York City, last year was at the second highest level in its 19-year history.

Academic employers also note that it has become extremely difficult to hire postdoctoral fellows; this indicates that the buffer of the postdoctoral pool established in the first part of the past decade largely has been used up. Department chairmen find that the number of applications for advertised junior faculty positions is down to a fifth or tenth of what it was about 1975. There can be little doubt that the supply of doctoral chemists is already marginal—or, more likely, insufficient.

Future demand for B.S. and M.S. chemists is much more difficult to assess because their net production is uncertain; many go on to obtain a Ph.D. degree. Moreover, the employment of B.S. chemists is not so clearly tied to chemical R&D as is that of Ph.D.'s. Demand for Ph.D.'s could be met by encouraging more top-quality B.S. chemists to pursue advanced studies. About half of B.S. chemists initially plan to attend graduate school, but only roughly a third eventually earn a Ph.D. Academic advisers at the college level therefore could play a major role in helping the profession balance supply and demand for Ph.D. chemists.

One major difficulty in projecting employment is the sensitivity of such estimates to federal policies. New legislation, such as the $1 billion energy research program once considered, can create thousands of jobs for chemists and other scientists. Similarly, plans to reduce federal expenditures by agencies with an important research support mission would eliminate a like number of jobs.

It cannot be overemphasized that research needs continuity and stability of effort and support. Chemists (or other scientists) who must leave basic research to stay employed cannot effectively return to it after a few years and may not want to do so. Basic research is strongly dependent on close communication among leading scientists and requires a grasp of a wide set of often seemingly unrelated concepts and facts, which can be developed only by intense concentration over a number of years. Once this grasp is acquired, it can be maintained with much less effort while the investigator is really able to make a contribution. But ideas and concepts change; after two or three years away from a field a scientist must begin anew, and productivity is interrupted not for two or three but for five to seven years.

Termination of research or vacillation in direction that leads to frequent changes of research areas, therefore, causes major inefficiencies. The effect of cutbacks is especially severe because the number of people engaged in basic chemical research is quite small, probably less than 10,000 in the entire U.S. Supposedly temporary cutbacks or unstable direction thus can have severe long-range effects, particularly since production of highly qualified and trained personnel is a time-consuming process with a lead time of four to seven years.

It is often argued that information derived from basic research is an international resource and that other countries successfully exploit basic research performed in the U.S. The effectiveness of basic research depends in part on the efficiency with which information is transferred in-house or from academic and other basic research laboratories to industry. New concepts are often conceived years before they appear in the literature; they are communicated orally, initially personally among interested scientists and later at scientific meetings. Cultivation of a strong academic-industry interface could give U.S. industry a competitive advantage through a shorter lead time in the exploitation of new concepts generated in the U.S.

There is some evidence that the U.S. is falling behind in scientific matters, particularly in scientific instrumentation. It is disturbing, for example, that four of the six regional facilities established by NSF in 1978 are being equipped with instrumentation designed and manufactured overseas.

Research basically is incremental or pyramidal in nature, with one discovery building upon another. To be effective, a large part of exploratory research should be in uncharted areas. Chemistry is a relatively mature science, and a number of its fields, especially those in which results can be predicted most readily and defended economically, are no longer likely to yield major new developments. They are, in a sense, like a well-worked-over mineral claim or oil field. Basic research must seek to be unconventional and extend itself into novel areas. But new areas usually will be more difficult and expensive to investigate, since it is human nature to exploit the easy areas first.

Therefore, it should be recognized that basic research is becoming more expensive. Lead times before discovery of useful new information may increase, despite the superior instrumentation now available. Most important, however, basic research requires continuity. It cannot be turned off or on at short notice and still be effective. □

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Gerhard G. Meisels has been chairman of the department of chemistry at the University of Nebraska since 1975. A native of Vienna, Austria, he received his graduate training and did postdoctoral work at Notre Dame. He joined Gulf Oil as a research chemist in 1956 and later performed research for Union Carbide before going to the University of Houston in 1965. He has been a member of the ACS Committee on Economic Status since 1977. This year he chaired a Gordon Conference on radiation chemistry and has just completed a term as chairman of the Committee on Fundamentals of the American Society for Mass Spectrometry. Meisels is the author of about 100 publications dealing with the chemistry of gaseous ions, mass spectrometry, photochemistry, ion-molecule reactions, unimolecular reactions of state-selected ions, and radiation chemistry.